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ASSISTANT COMMISSIONER FOR PATENTS
WASHINGTON, DC 20231

Transmitted herewith for filing is the patent application of:

Inventors: **Salvatore COFFA**
Sebania LIBERTINO
Mario SAGGIO
Ferruccio FRISINA

For : SEMICONDUCTOR DEVICE FOR ELECTRO-OPTIC APPLICATIONS, METHOD FOR MANUFACTURING SAID DEVICE AND CORRESPONDING SEMICONDUCTOR LASER DEVICE

jc714 U.S. PTO 09/653390 09/01/00

Enclosed are:

[X] Patent Application: 18 pages, 27 claims.
[X] 6 Sheets of drawings.
[X] A Preliminary Amendment.
[X] Citation Under 37 CFR 1.97 and PTO-1449.
[X] Submission of Proposed Drawing Modification.

The Declaration and Filing Fee are **NOT ENCLOSED.**

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Date: September 1, 2000

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of: **COFFA ET AL.**	CERTIFICATE OF MAILING BY "EXPRESS MAIL" "EXPRESS MAIL" MAILING LABEL NUMBER EL551652058US
Serial No. **Not yet assigned**	DATE OF DEPOSIT September 1, 2000
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For: **SEMICONDUCTOR DEVICE FOR ELECTRO-OPTIC APPLICATIONS, METHOD FOR MANUFACTURING SAID DEVICE AND CORRESPONDING SEMICONDUCTOR LASER DEVICE**	Eric Link (TYPED OR PRINTED NAME OF PERSON MAILING PAPER OR FEE) Eric Link (SIGNATURE OF PERSON MAILING PAPER OR FEE)

PRELIMINARY AMENDMENT

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

Prior to the calculation of fees and examination of the present application, please enter the amendments and remarks set out below.

In the Drawings:

Submitted herewith is a request for proposed drawing modifications as indicated in red ink to label FIGS. 1, 2a, 2b, 3a, 3b and 11 as prior art.

In the Claims:

Please cancel Claims 1-27.

Please add new Claims 28-54.

28. A semiconductor device for electro-optic applications comprising:

a semiconductor substrate; and

a doped P/N junction integrated with said semiconductor substrate, said P/n junction comprising a depletion layer and having a shape defining a waveguide, said depletion layer comprising at least one rare-earth material for providing a coherent light source.

29. A semiconductor device according to Claim 28, further comprising a biasing device connected to said doped P/N junction for reverse biasing.

30. A semiconductor device according to Claim 28, wherein said at least one rare-earth material in the depletion layer of said doped P/N junction forms a base-collector region for a bipolar transistor.

31. A semiconductor device according to Claim 28, wherein said at least one rare-earth material comprises erbium.

32. A semiconductor device according to Claim 28, further comprising a protective layer partially on said doped P/N junction, said protective layer having a lower dielectric constant than a dielectric constant of said doped P/N junction.

33. A semiconductor device according to Claim 28, further comprising a buried reflecting layer to delimit a bottom of the waveguide.

34. A semiconductor device according to Claim 28, wherein said semiconductor substrate comprises a silicon on insulator (SOI) substrate.

35. A semiconductor device according to Claim 28, further comprising an epitaxial layer on said semiconductor substrate.

36. A semiconductor device according to Claim 28, wherein said doped P/N junction is stacked so that the shape of the waveguide is a ribbed elongated structure projecting from a surface of said semiconductor substrate.

37. A semiconductor device according to Claim 28, wherein said semiconductor substrate comprises silicon.

38. A semiconductor laser device comprising:

a semiconductor substrate;

a doped P/N junction integrated with said semiconductor substrate, said P/n junction comprising a depletion layer and having a shape defining a waveguide, said depletion layer comprising at least one rare-earth material for providing a coherent light source; and

a biasing device connected to said doped P/N junction.

39. A semiconductor laser device according to Claim 38, wherein said biasing device comprises a bipolar transistor including a base-collector region formed by said doped P/N junction.

40. A semiconductor laser device according to Claim 38, wherein said biasing device reverse biases said doped P/N junction.

41. A semiconductor laser device according to Claim 38, wherein said at least one rare-earth material comprises erbium.

42. A semiconductor laser device according to Claim 38, further comprising a protective layer partially on said doped P/N junction, said protective layer having a lower dielectric constant than a dielectric constant of said doped P/N junction.

43. A semiconductor laser device according to Claim 38, wherein said doped P/N junction is stacked so that the shape of the waveguide is a ribbed elongated structure projecting from a surface of said semiconductor substrate.

44. A semiconductor laser device according to Claim 38, wherein said semiconductor substrate comprises a silicon on insulator (SOI) substrate.

45. A semiconductor laser device according to Claim 38, further comprising an epitaxial layer on said semiconductor substrate.

46. A semiconductor laser device according to Claim 38, further comprising a buried reflecting layer to delimit a bottom of the waveguide.

47. A semiconductor laser device according to Claim 38, wherein said semiconductor substrate comprises silicon.

48. A method for manufacturing a semiconductor device for electro-optic applications, the method comprising:

forming a P/N junction with a semiconductor substrate, the P/N junction comprising a depletion layer; and

doping the depletion layer with at least one rare-earth material.

49. A method according to Claim 48, further comprising providing a biasing device for biasing the P/N junction.

50. A method according to Claim 48, wherein forming the P/N junction comprises forming the P/N junction to have a shape defining a waveguide.

51. A method according to Claim 50, wherein the shape of the waveguide is a ribbed elongated structure projecting from a surface of the semiconductor substrate.

52. A method according to Claim 48, wherein forming the P/N junction comprises:

providing a semiconductor substrate comprising an N-type conductivity; and

selectively doping with P-type dopants an upper surface of the semiconductor substrate to define a first doped region.

53. A method according to Claim 52, wherein doping the semiconductor substrate with at least one rare-earth material forms a rare-earth doped region in the depletion layer under the first doped region.

52. A method according to Claim 49, wherein providing the biasing device comprises forming a bipolar transistor in the semiconductor substrate, the bipolar transistor including a base-collector region formed by the depletion layer.

51. A method according to Claim 48, wherein the at least one rare-earth material comprises erbium.

52. A method according to Claim 48, further comprising forming a protective layer partially on the doped P/N junction, the protective layer having a lower dielectric constant than a dielectric constant of the doped P/N junction.

53. A method according to Claim 48, wherein the semiconductor substrate comprises a silicon on insulator (SOI) substrate.

54. A method according to Claim 48, further comprising an epitaxial layer on the semiconductor substrate.

REMARKS

It is believed that all of the claims are patentable over the prior art. Accordingly, after the Examiner completes a thorough examination and finds the claims patentable, a

In re Patent Application of:
COFFA ET AL.
Serial No. **Not yet assigned**
Filing Date: **Herewith**

Notice of Allowance is respectfully requested in due course. Should the Examiner determine any minor informalities that need to be addressed, he is encouraged to contact the undersigned attorney at the telephone number below.

Respectfully submitted,

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SEMICONDUCTOR DEVICE FOR ELECTRO-OPTIC APPLICATIONS, METHOD FOR MANUFACTURING SAID DEVICE AND CORRESPONDING SEMICONDUCTOR LASER DEVICE

Field of the Invention

The present invention relates to semiconductor devices, and, more particularly, to a semiconductor device for electro-optic applications and a corresponding semiconductor laser device. The semiconductor device includes a rare-earth ions doped P/N junction integrated on a semiconductor substrate.

Background of the Invention

Silicon is the material most commonly used for manufacturing advanced microelectronic devices. Current electronic manufacturing technology may be considered mature, but a new optical communication technology is emerging. In optical communication technology, basic information is carried by optical signals having standard wavelengths in a range between 1.3 and 1.55 microns.

It would be highly desirable to combine optical and electronic functions in silicon to implement optical-electronic applications in a single semiconductor device. Significant progress has recently been made in the combination of electronic and optical technologies for manufacturing semiconductor optical devices operating at near infrared wavelengths.

A few examples may be found in the following three articles: 1)optical waveguides can be made with low losses, as disclosed by Fisher et al. in the IEEE article titled "Photonics Technology Letters" 8, 647 (1996); 2) light emitting diodes based on erbium (Er) doping have been demonstrated, as reported by Coffa et al. in the MRS Bulletin on "Si-based optoelectronics" 23, 4, edited by Materials Research Society, S. Coffa and L. Tsybeskov guest editors; and 3) optical switches based on an electro-optic effect can be formed on silicon, as disclosed by Cutolo et al. in Lightwave Technology 15, 505 (1997)

There is, however, a main limitation for using silicon in optical applications such as, for example, optical interconnections intra-chip or between chips. This main limitation is due to the lack of a coherent light source, i.e., a silicon-based laser. Silicon is not suitable as an efficient light emission due to its indirect band gap.

Several approaches have been used to try to overcome this problem. The use of optical doping of silicon with rare earth ions, with or without impurities such as O, F, and N presents several interesting features not only for manufacturing efficient light emitting diodes, but also for the attempt of forming a silicon-based laser. Efficient room temperature electro-luminescence from erbium-oxygen co-doped silicon diodes has been reported. Moreover, the long spontaneous lifetime of the first excited state of erbium (about 1 ms), can insure a population inversion which is needed for an efficient light emission.

To fully understand all the aspects of the present invention, a schematic diagram of the mechanisms connected to electrical pumping of erbium

ions are shown in Figures 1, 2a, 2b, 3a and 3b. A room temperature electro-luminescence at a 1.54 μm wavelength can be achieved when Er ions are incorporated into a P/N diode junction.

A known approach is disclosed in U.S. Patent No. 5,107,538 that relates to an optical waveguide system comprising a rare-earth Si-based optical device. This device, however, only produces a luminescence at a temperature close to 4K and the efficiency of the light emission is extremely reduced at room temperature. Moreover, the '538 patent fails to disclose the use of rare-earth ions located inside the junction. Therefore, the light emission obtained by this technology is insufficient for implementing commercial devices, and no electro-optical products on silicon are currently known to be on the market.

Summary of the Invention

In view of the foregoing background, an object of the present invention is to provide a semiconductor device having structural and functional features to allow implementation of a coherent light emitting source into a semiconductor substrate that includes a rare-earth ions doped junction. The semiconductor substrate may be silicon.

Another object of the present invention is to allow optical interconnections intra-chip or between chips.

Yet another object of the present invention is to provide a single chip integrated semiconductor laser device. The semiconductor substrate may be silicon.

A further object of the present invention is to provide an electrically pumped optical amplification and laser action at room temperature.

These and other objects, advantages and features are provided by an electrically pumped optical amplification, and laser action using erbium-doped crystalline silicon. The semiconductor device according to the present invention comprises an erbium-doped P/N junction integrated within a semiconductor cavity or waveguide.

The invention allows combination of impact excitation of Er ions by hot carriers in the depletion layer of the reverse biased junction with a proper Er doping and electric field distribution. Electro-optical amplification is provided when the Er ions are within the depletion layer of the semiconductor device. The Er ions provide proper acceleration of the carriers before they enter the Er-doped region.

Accordingly, the present invention is directed to a semiconductor device, a semiconductor laser device, and a method for manufacturing a semiconductor device.

Brief Description of the Drawings

The features and the advantages of the semiconductor device and corresponding manufacturing method according to the invention, will become clear from the following description of a preferred embodiment given as a non-limiting example with reference to the attached drawings.

Figure 1 shows the 4f electronic levels of an erbium ion and the transitions giving rise to a 1.54 μm light emission according to the prior art;

Figures 2a and 2b respectively show the excitation mechanism for rare earth ions in crystalline silicon according to the prior art, with the specific case of Er ions being illustrated;

Figures 3a and 3b respectively show the de-excitation mechanisms for rare earth ions in crystalline silicon according to the prior art;

Figures 4 to 8 are schematic cross sectional views of a semiconductor device according to the present invention during subsequent manufacturing process steps;

Figure 9 shows a cross-sectional perspective view of a semiconductor device according to the present invention;

Figure 10 shows a schematic vertical cross-sectional view of the semiconductor device of Figure 9 showing the location of the rare earth ions needed to achieve laser action;

Figure 11 shows a schematic view of a dark region in the central depletion layer where Er ions are pumped by impact excitation according to the prior art;

Figure 12 shows a diagram of the doping concentration versus doping depth for the semiconductor device according to the present invention; and

Figure 13 shows a diagram of the electric field versus doping depth for the semiconductor device according to the present invention.

Detailed Description of the Preferred Embodiments

With reference to the enclosed drawings, reference 1 is a semiconductor device formed according to the present invention for electro-optic applications. The semiconductor material is preferably silicon. The process for manufacturing the semiconductor device 1 will now be disclosed. The specific features of the semiconductor device 1 will be discussed in greater detail below.

The manufacturing process will now be described step by step. A silicon-on-insulator (SOI)

wafer is provided as a substrate 2 for the semiconductor device 1. A known SIMOX or BESOI technology may be used to provide the SOI wafer. However, instead of using a SOI wafer, the substrate for the semiconductor device 1 may simply comprise a double layer of a semiconductor material. For instance, the double layer may include a first highly doped substrate layer and a second upper lightly doped epitaxial layer. In such a case, the lower substrate layer would have a lower refraction index and would act as a reflective layer for the incident light.

The SOI substrate 2 is formed by a first lower monocrystalline layer 3, an oxide layer 4, and a second upper monocrystalline layer 5. The first and the second monocrystalline layers may be doped with a dopant having a first conductivity type, for instance N-type. The second upper layer 5 is less doped than the first lower layer 3. An oxide layer 7 is grown on top of the substrate 2, that is, over the second upper monocrystalline layer 5.

A photolitographic process step is then provided to define an aperture 8 in the oxide layer 7 and to selectively form a doped region 10. The dopant used for this region 10 has an opposite conductivity type, for instance P-type. A masked implantation step of B ions in the upper layer 5 allows formation of this P+ doped region 10, as shown in Figure 5. Through the same mask, a rare-earth ions doped region 9 is formed. For example, an ion implantation process step is performed to obtain a region 9 under the P+ doped region 10, as shown in Figure 5. Preferably, the rare earth ions are selected from the group comprising erbium (Er). A proper co-doping with other impurities, such as O, F, and N may also be used.

Rare earths (RE) incorporation can be achieved using different techniques, such as ion implantation, molecular beam epitaxy (MBE), chemical vapor deposition (CVD), ion assisted deposition, and Si-epitaxial regrowth on shallow RE-doped regions. As readily appreciated by one skilled in the art, the different techniques may require different process steps.

The region 9 is an N-type doped region and the stack formed by the regions 5, 9 and 10 form substantially a P/N diode junction. The semiconductor device structure of the present invention is similar to a base-collector junction of a bipolar transistor.

Advantageously, all the implanted Er ions are incorporated in the depletion layer of the P/N junction formed by the regions 5, 9 and 10, as clearly shown in Figure 13. Alternatively, all the implanted Er ions are incorporated in the depletion layer of the base-collector region of the bipolar transistor.

A masked etching process step is then performed to protect the stacked regions 5, 9 and 10 and to etch the semiconductor at both sides of the regions 9 and 10. This is done to provide a projecting stack region 6 formed just by the P+ doped region 10 and part of the region 5. A dry or wet etching step may be used for etching the semiconductor.

A protective oxide layer 11 is deposited over the resulting stack, as shown in Figure 6. This protective oxide layer 11 covers the stack 6, which is formed by the regions 9 and 10, and has a lower dielectric constant. As a result, a laser cavity or waveguide is obtained on silicon with the oxide layer 11 delimiting the sides of the waveguide and the buried oxide layer delimits the bottom of the waveguide.

The device obtained with the inventive method allows light to be confined in a two dimensional plane perpendicular to the direction of propagation of the electromagnetic wave. Hence, the semiconductor region containing the gain medium, i.e., the erbium ions concentration, is surrounded by a cavity structure or waveguide delimited by a material having a lower refractive index.

Referring to Figure 9, a waveguide having substantially a ribbed elongated structure is shown. However, other examples may be proposed such as planar waveguides in which the lateral confinement is obtained. For instance, shallow trenches may be filled by a lower refractive index material, or by heavily doped regions, which are some of the many possible alternatives.

The manufacturing process is continued using another masked implantation step of N-type dopants. Using a suitable mask (not shown), a portion of the protective oxide layer 11 is removed over the upper substrate layer 5, which is close to the stack 6. N-type dopants, for instance P-type ions, are implanted in the upper layer 5 to form contact N+ regions 19, as shown in Figure 7.

An additional oxide layer is deposited over the whole semiconductor portion and a masked process is used to define contacts openings over the P+ region 10 and over the N+ regions 19. A final deposition step of a metal layer, followed by a lithography step, is performed to define the metal contacts on the P+ and N+ regions 10 and 19, as shown in Figure 8. The resulting structure is clearly shown in Figure 9, which is a schematic vertical cross-section and perspective view of the semiconductor device 1 including a cavity or waveguide and a P/N diode junction.

An evaluation of the specific features of the semiconductor device structure 1 obtained according to the process previously disclosed will now be discussed. Er ions can be effectively pumped by electron-hole (e-h) recombination under a forward bias diode operation at temperatures below 200K. However, a phenomenon know as Auger de-excitation and back energy transfer strongly reduces the efficiency of light emission at higher temperatures.

According to the invention, these negative effects are fully inhibited under reverse bias conditions, thereby allowing strong light emission to be achieved at room temperature. In fact, all of the implanted Er ions are incorporated in the depletion layer of a P/N junction or, alternatively, in the depletion layer of the base collector region of the bipolar transistor.

Since rare earth ions are incorporated in a depletion layer, electrical pumping of these ions can be achieved in different device structures, such as Schottky diodes, bipolar transistors, MOSFET devices, etc. Moreover, a sufficient acceleration space is provided before carriers enter the Er doped regions. Acceleration is provided either by tunneling in a reverse biased P/N junction or injected by the emitter-base junction of a transistor. Following this approach population inversion will be extended to all of the Er ions.

After having achieved laser operation at room temperature, an efficient electronic pumping effect can be maintained at room temperature according to the present invention. Therefore, a semiconductor laser device may be formed incorporating the rare-earth ions in a laser cavity which presents low losses at the emission wavelength.

In this respect, the use of a silicon substrate is certainly an advantage since a silicon semiconductor is almost transparent at the 1.54 μm wavelength. Integrated silicon waveguides using silicon as the core material and silicon oxide (SiO2) as claddings have already been manufactured with losses as low as 0.1 dB/cm.

According to the invention, rare-earth ions doping of these waveguides within an integrated device structure allowing electrical pumping of the rare earth ions can be used to produce the laser cavity. Diode operation at the diode breakdown threshold results in an intense light emission at 1.54 μm, characterized by an internal quantum efficiency of about 0.1%. It may be demonstrated that in such a structure the Er ions are pumped to the excited levels as a result of impact excitation by hot carriers. Impact excitation with hot carriers is provided to invert Er population rather than electron-hole recombination.

During pumping, the losses due to the free electrons will be fully inhibited and the laser action would benefit from the extremely low losses that intrinsic silicon exhibits at 1.54 μm since the Er ions are embodied in the depletion layer of a junction. This amplification gain at 1.54 μm can overcome waveguide losses and laser action can be achieved if a cavity reflector structure is formed.

To discuss how to obtain a proper laser action, reference is still made to the schematic view of Figure 9. The semiconductor device 1 is formed using an SOI substrate 2 and the process previously disclosed. The stacked P/N junction is doped with rare earth ions. Er pumping will result in light emission coupled to the fundamental modes of the cavity. This structure could be used both as an electrically pumped

optical amplifier or as a laser if proper feedback is applied. Split output and input waveguide facets, or distributed Bragg reflector structures can be suitably used to provide the feedback needed for laser action.

The most important limitation that the invention has overcome was an insufficient Er concentration to achieve a laser action at 1.54 μm in the Er-doped silicon substrate using an integrated waveguide. Since erbium in silicon acts as a donor, a high concentration of free electrons in the region where erbium sits is present. To incorporate high Er concentration in silicon semiconductor, co-doping with impurities such as O and F plays a fundamental role. However, this co-doping also produces a strong donor activity of the Er ions resulting in a high concentration of free electrons in the region where Er sits.

When erbium is incorporated within a structure, such as the channel waveguide previously disclosed, the strong concentration of free electrons will produce by the plasma dispersion effect strong losses which would make the achievement of a net gain impossible. Free carrier concentration has to be maintained below $10^{17}/cm^3$ to achieve low losses.

Due to the donor behavior of Er, both the real and the imaginary part of the refractive index are strongly affected by the high free carrier concentration, and the mode tends to escape from the region where Er sits. Moreover, effective losses as high as approximately 200 cm^{-1} can be obtained.

A problem to be solved results from the use of impact excitation of Er ions in reverse biased P/N junctions because of the existence of a dark region in the central portion of the depletion layer where carriers do not have enough energy to pump Er ions.

It has been experimentally demonstrated by Coffa et al., Appl. Phys. Lett. 73, 93 (1998) that a region of about 400 Å in the central portion of about a 1000 Å thick depletion layer is dark. Such a behavior is schematically shown in Figure 11. The peculiar feature of impact excitation is due to the existence of a threshold. If the energy of the carrier is lower than that required to promote the Er ions to the first excited state (0.8 eV) the process cannot occur. A second problem is that the Er ions sitting outside the depletion layer cannot be pumped by this mechanism. Consequently, they will not be excited but will adsorb light at 1.54 μm.

The Er population cannot be inverted in the central part of the diode since the energy of the carriers, produced by band to band tunneling and then accelerated by the strong electric field present at the junction, is not sufficient to pump Er. An effective pumping of Er ions to achieve population inversion and the capability of maintaining low losses in the Er doped waveguides is achieved by the inventive structure. How the invention solves these two problems is examined in detail below.

The inventive device and method solve all the previously discussed problems by incorporating all the implanted Er ions in the depletion layer of the P/N junction and providing: 1) a sufficient acceleration space before carriers enter the Er-doped regions, 2) population inversion extended to all the Er ions, and 3) inhibition of loss due to free electrons because the erbium ions are embodied in the junction depletion layer. The laser action would benefit from the extremely low loss that intrinsic Si exhibits at 1.54 µm. Er has been placed where the maximum of the mode sits. Since the erbium ions are in the depletion

region, the free carrier concentration strongly decreases and an effective loss as low as 0.6 cm^{-1} has been evaluated.

THAT WHICH IS CLAIMED IS:

1. Semiconductor device for electro-optic applications of the type including at least a rare-earth ions doped P/N junction integrated on a semiconductor substrate, a cavity or a waveguide and a coherent light source, characterised in that said coherent light source is obtained incorporating said rare-earth ions in the depletion layer of said P/N junction.

2. Semiconductor device according to claim 1, wherein said P/N junction is reverse biased.

3. Semiconductor device according to claim 1, wherein said rare-earth ions doped P/N junction is the base-collector region of a bipolar transistor.

4. Semiconductor device according to claim 1, wherein said rare-earth ions are Erbium ions.

5. Semiconductor device according to claim 1, wherein said cavity or waveguide includes said P/N junction and is partially enveloped by a protective layer having a lower dielectric constant with respect to said junction.

6. Semiconductor device according to claim 1, wherein a buried reflecting layer is provided to delimit the bottom of said waveguide.

7. Semiconductor device according to claim 1, wherein said semiconductor substrate is a SOI substrate.

8. Semiconductor device according to claim 1, wherein said semiconductor substrate is an epitaxial layer covering an heavily doped substrate layer.

9. Semiconductor device according to claim 1, wherein said cavity or waveguide has a rib elongated structure projecting from the semiconductor surface.

10. Semiconductor device according to claim 1, wherein said semiconductor is Silicon.

11. Semiconductor laser device comprising at least a rare-earth ions doped P/N junction integrated on a semiconductor substrate, a cavity or waveguide and a coherent light emitting source, characterised in that said device comprises includes a biasing device and incorporates said rare-earth ions in the depletion layer of said P/N junction.

12. Semiconductor laser device according to claim 10, wherein said biasing device is a bipolar transistor and said P/N junction is the base-collector region of said bipolar transistor.

13. Semiconductor laser device according to claim 10, wherein said P/N junction is reverse biased.

14. Semiconductor laser device according to claim 10, wherein said rare-earth ions are Erbium ions.

15. Semiconductor laser device according to claim 10, wherein said cavity or waveguide includes said P/N junction and is partially enveloped by a protective layer having a lower dielectric constant with respect to said junction.

16. Semiconductor laser device according to claim 10, wherein said cavity or waveguide has a rib elongated structure projecting from the semiconductor surface.

17. Semiconductor laser device according to claim 10, wherein said semiconductor substrate is a SOI substrate.

18. Semiconductor laser device according to claim 10, wherein said semiconductor substrate is an epitaxial layer covering an heavily doped substrate layer.

19. Semiconductor laser device according to claim 10, wherein a buried reflecting layer is provided to delimit the bottom of said waveguide.

20. Semiconductor laser device according to claim 10, wherein said semiconductor is Silicon.

21. A method for manufacturing a semiconductor device for electro-optic applications, said device including at least a rare-earth ions doped P/N junction integrated on a semiconductor substrate, characterised in that of providing a cavity or waveguide in said semiconductor substrate and a coherent light emitting source incorporating said rare-earth ions in the depletion layer of said P/N junction.

22. Method according to claim 21, wherein a biasing device is also provided to bias said P/N junction.

23. Method according to claim 21, wherein said biasing device is a bipolar transistor and said rare-earth ions doped P/N junction forms the base-collector region of said bipolar transistor.

24. Method according to claim 21, wherein said rare-earth ions are Erbium ions.

25. A method for manufacturing a semiconductor laser device for electro-optic applications, said device including at least a rare-earth ions doped P/N junction integrated on a semiconductor substrate, characterised in that of providing a cavity or waveguide in said semiconductor substrate and a coherent light emitting source comprising a biasing device and a concentration of said rare-earth ions in the depletion layer of said P/N junction.

26. Method according to claim 25, wherein said biasing device is a bipolare transistor and said rare-earth ions doped P/N junction forms the base-collector region of said bipolar transistor.

27. Method according to claim 25, wherein said rare-earth ions are Erbium ions.

SEMICONDUCTOR DEVICE FOR ELECTRO-OPTIC APPLICATIONS, METHOD FOR MANUFACTURING SAID DEVICE AND CORRESPONDING SEMICONDUCTOR LASER DEVICE

Abstract of the Disclosure

A semiconductor device for electro-optic applications includes a rare-earth ions doped P/N junction integrated on a semiconductor substrate. The semiconductor device may be used to obtain laser action in silicon. The rare-earth ions are in a depletion layer of the doped P/N junction, and are for providing a coherent light source cooperating with a waveguide defined by the doped P/N junction. The doped P/N junction may be the base-collector region of a bipolar transistor, and is reverse biased so that the rare-earth ions provide the coherent light.

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of:
COFFA ET AL.

Serial No. **Not yet assigned**

Filing Date: **Herewith**

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Eric Link

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SUBMISSION OF PROPOSED MODIFICATIONS TO DRAWINGS

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

Submitted herewith is a request for proposed drawing modifications as indicated in red ink to label FIGS. 1, 2a, 2b, 3a, 3b and 11 as prior art.

Respectfully submitted,

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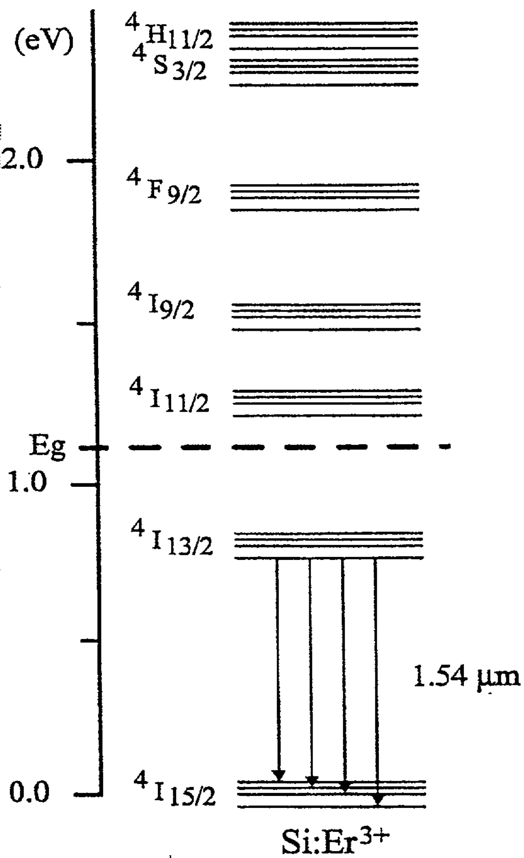
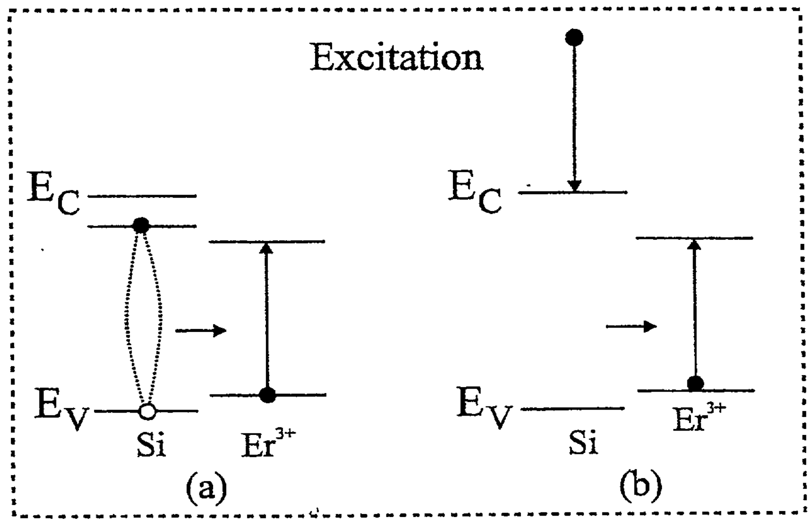


Fig. 1
(PRIOR ART)



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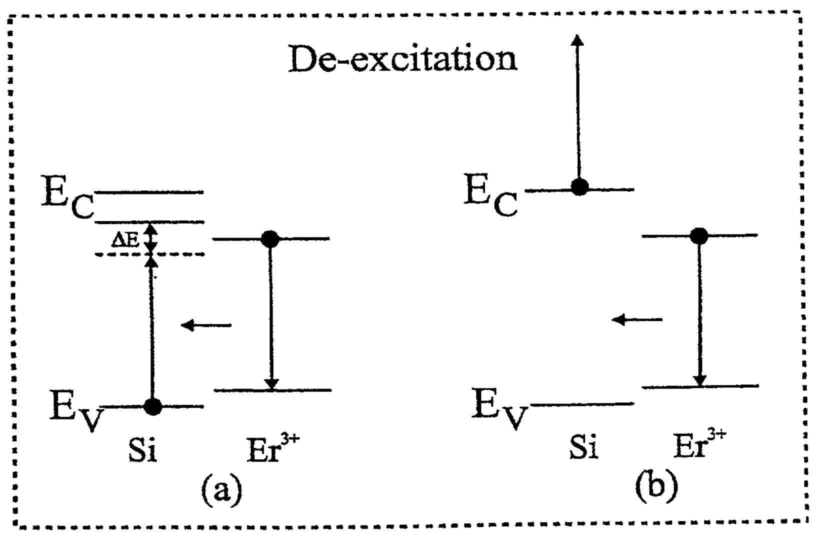

Fig. 3
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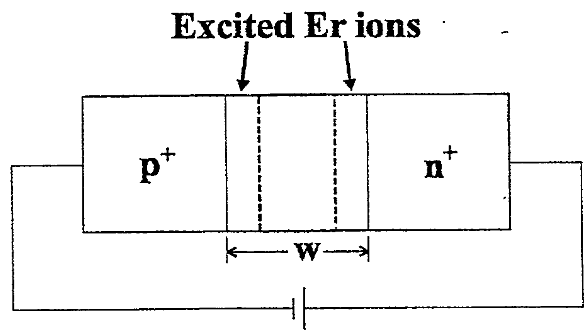

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(PRIOR ART)

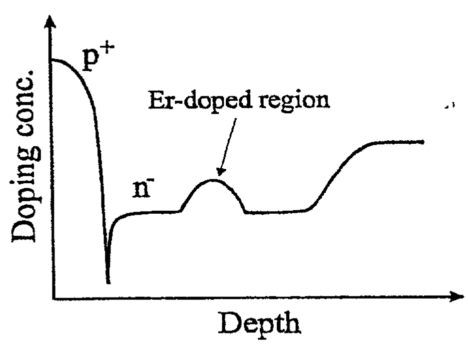


Fig. 12

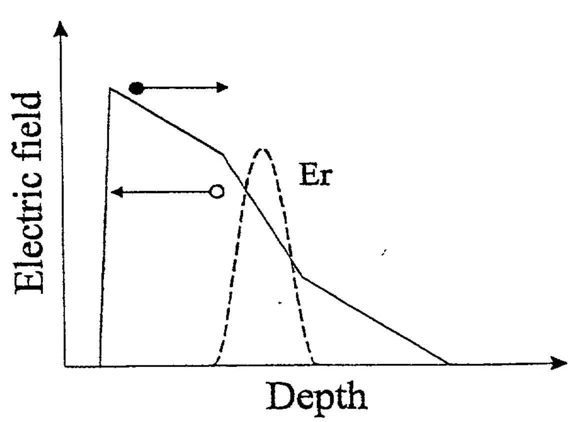


Fig. 13

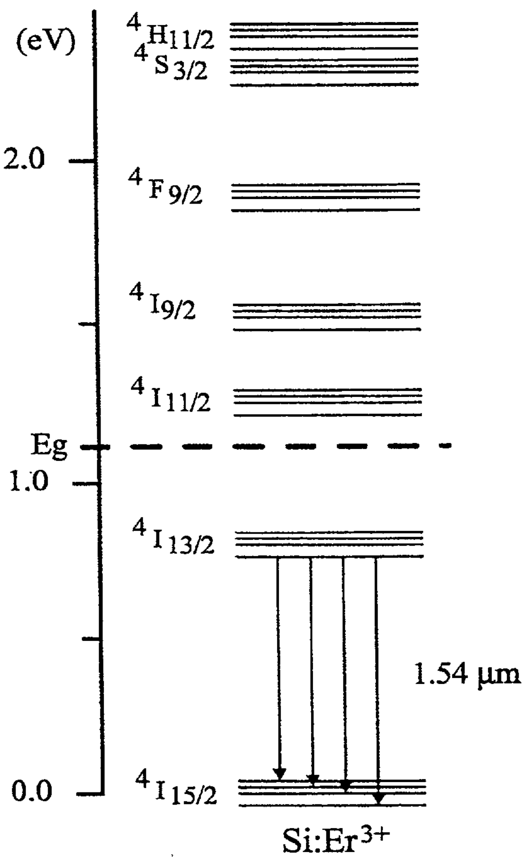


Fig. 1

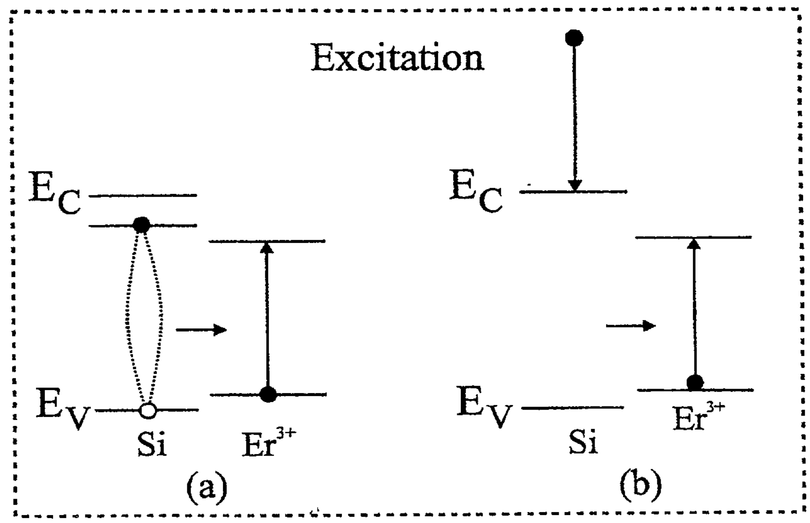


Fig. 2

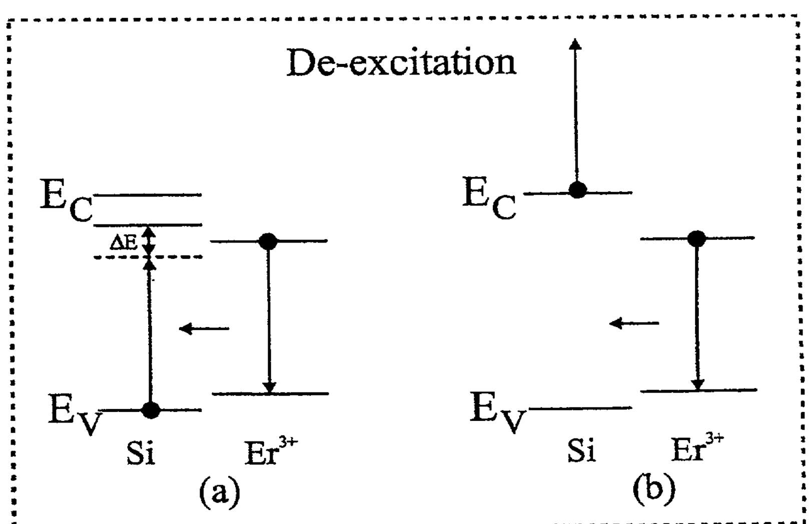
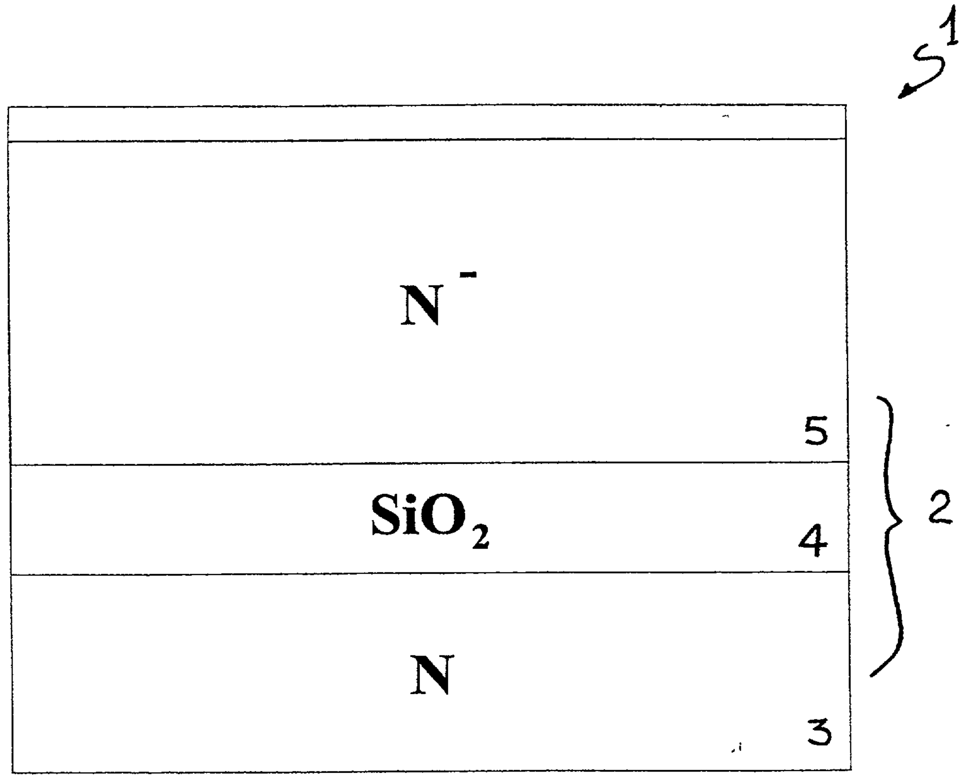


Fig. 3



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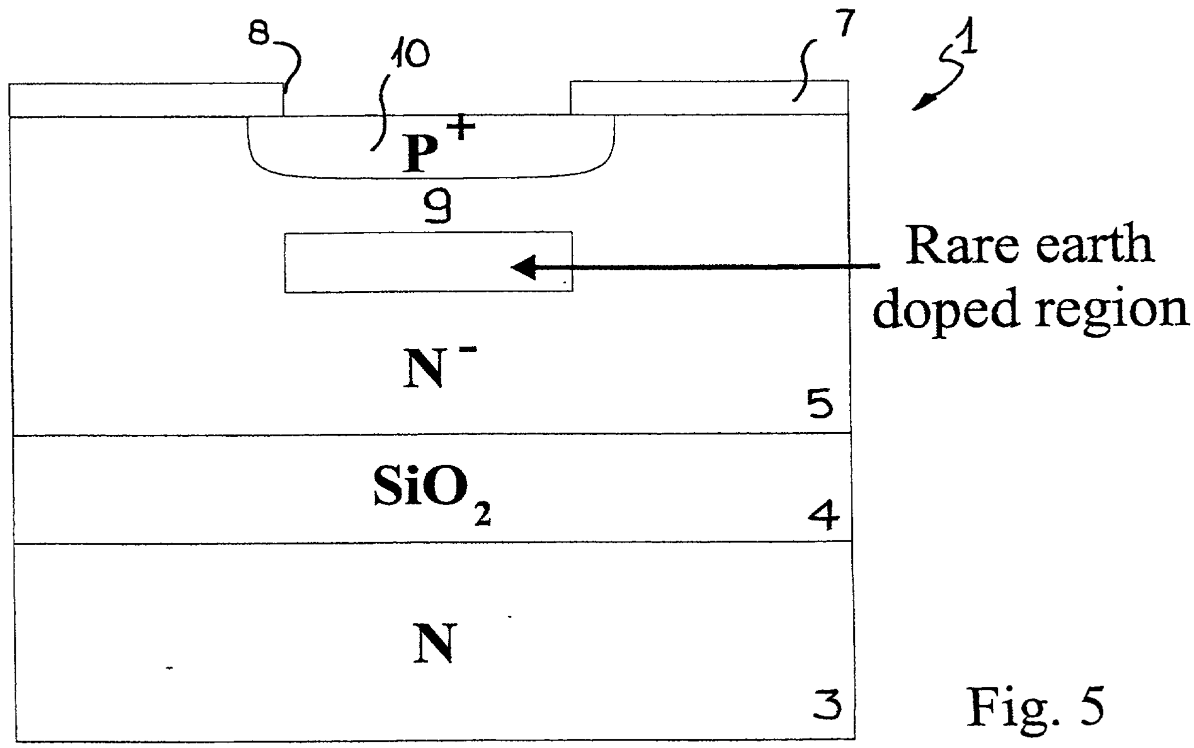


Fig. 5

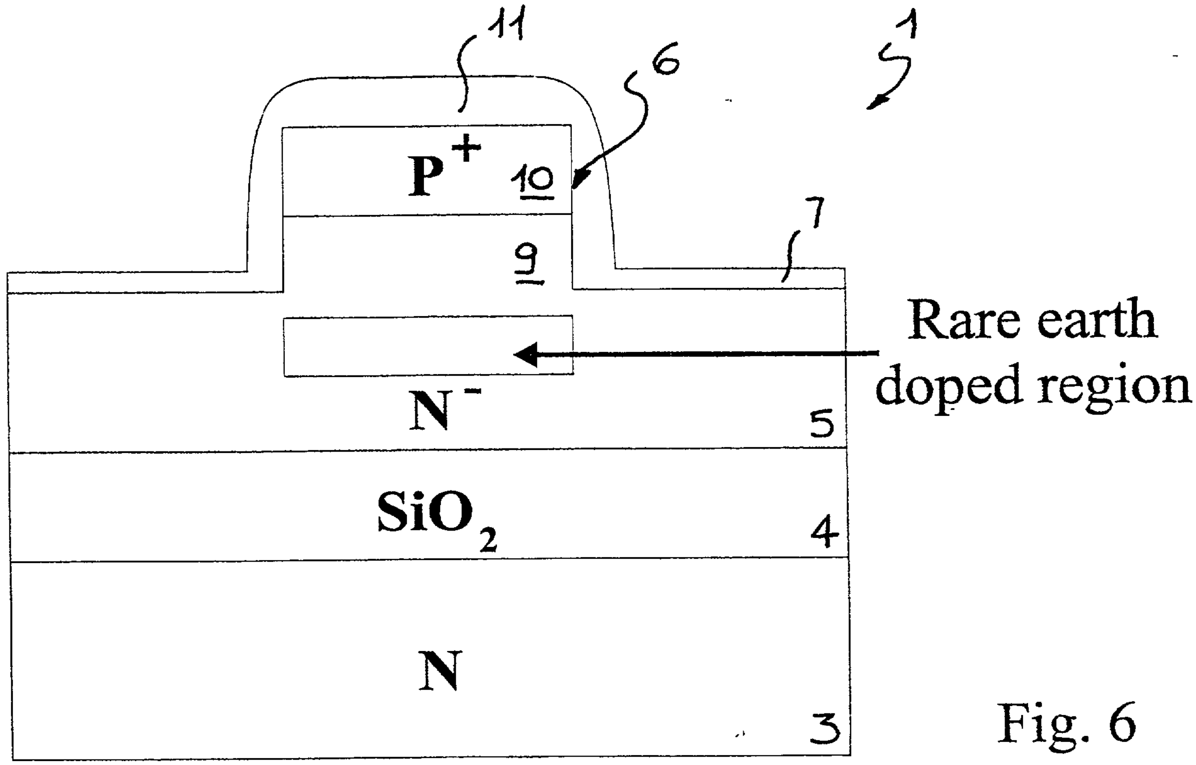

11
6
1
P+
10
9
7
Rare earth doped region
N-
5
SiO2
4
N
3

Fig. 6

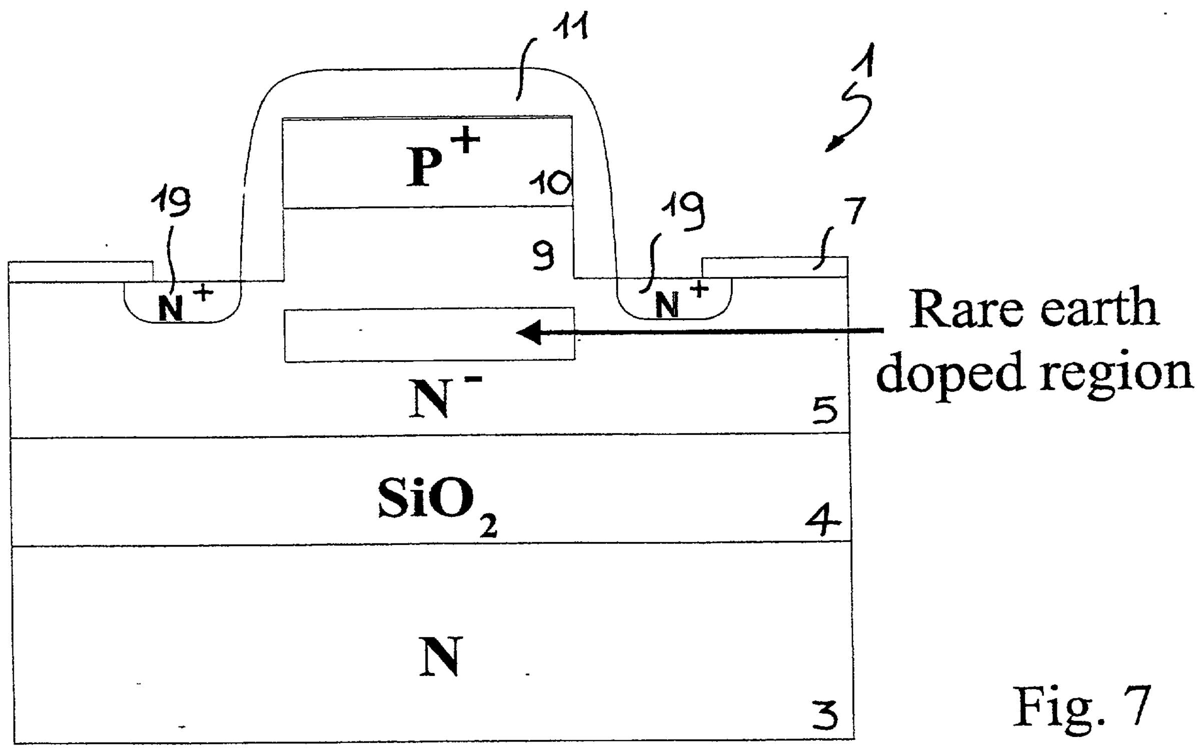

11
1
P+
10
19
19
7
9
N+
N+
Rare earth doped region
N-
5
SiO2
4
N
3

Fig. 7

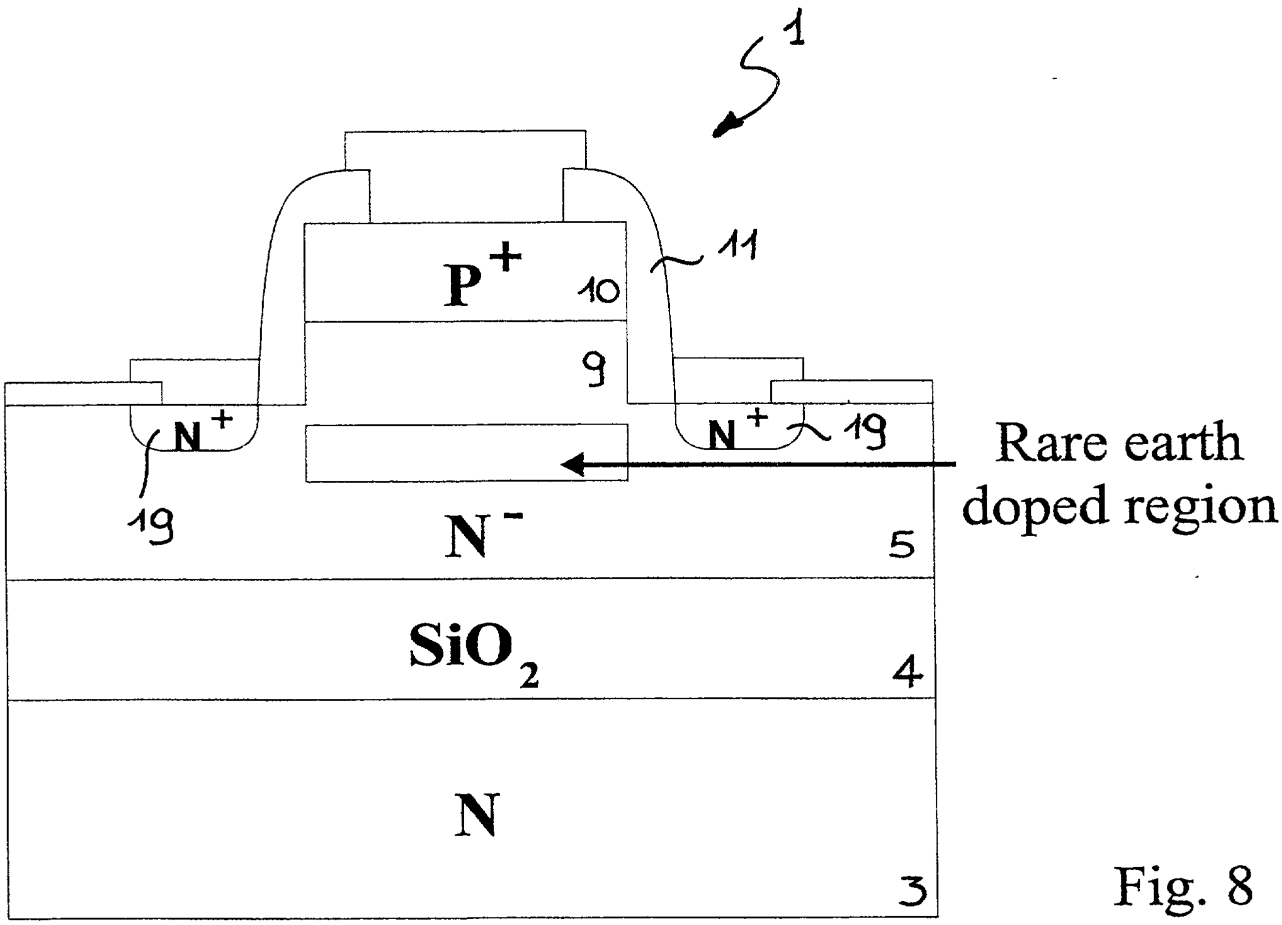
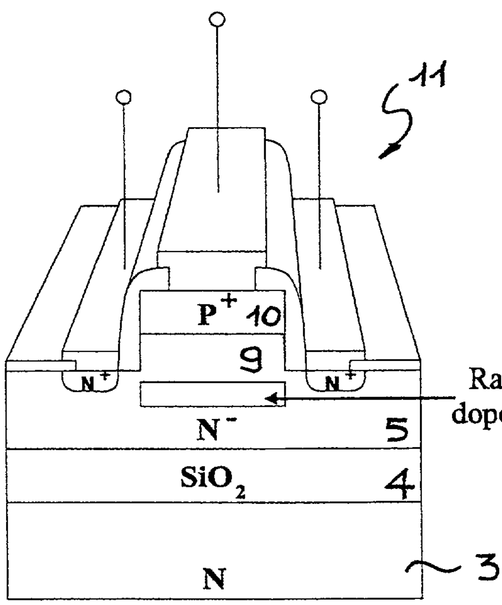
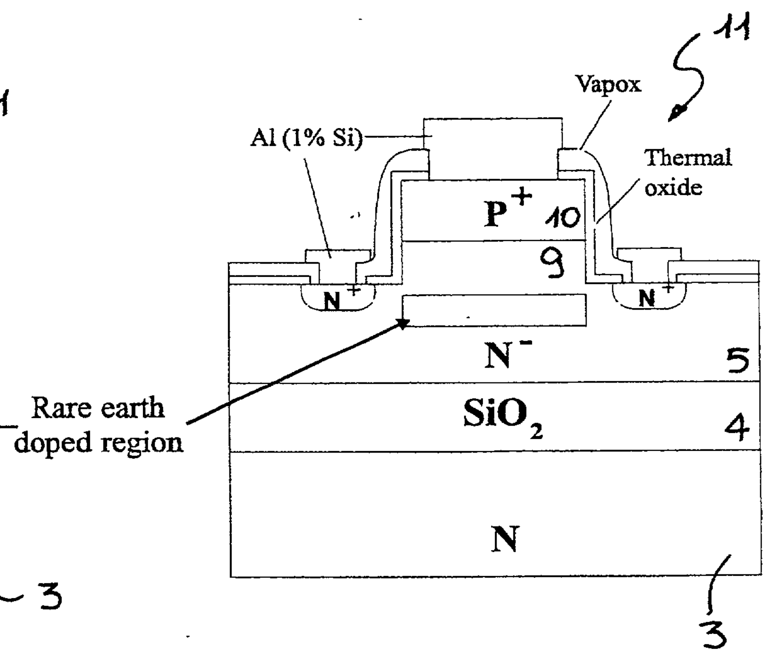


Fig. 8



11
P+ 10
9
N+
N+
N-
5
SiO2
4
N
3
Rare earth doped region

Fig. 9



11
Vapox
Al (1% Si)
Thermal oxide
P+ 10
9
N+
N+
N-
5
SiO2
4
N
3

Fig. 10

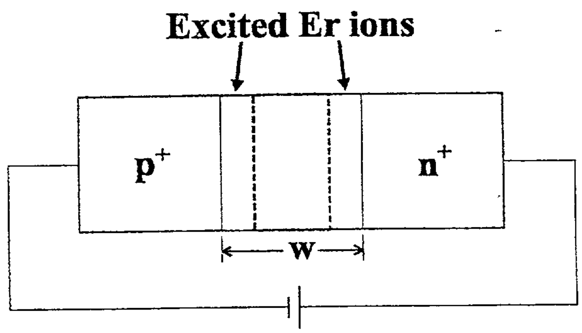


Fig. 11

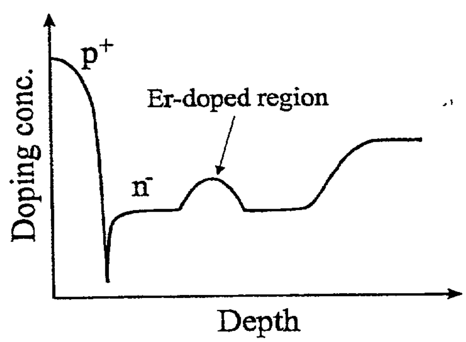


Fig. 12

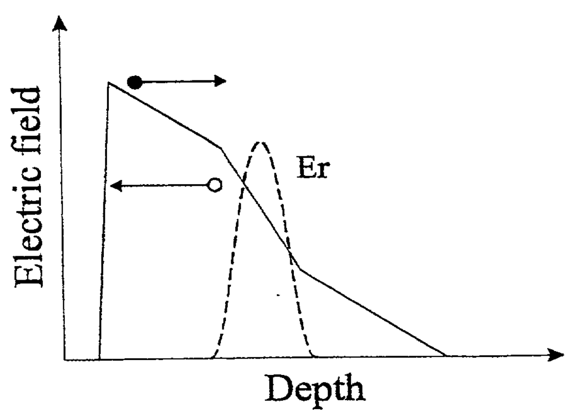


Fig. 13